Measurements of Double-Spin Asymmetries in SIDIS of Longitudinally Polarized Leptons off Transversely Polarized Protons

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Abstract. A Fourier analysis of double-spin azimuthal asymmetries measured at HERMES in semi-inclusive deep-inelastic scattering of longitudinally polarized leptons off tranversely polarized protons is presented for pions and charged kaons. The extracted amplitudes can be interpreted as convolutions of transverse momentum-dependent distribution and fragmentation functions and provide sensitivity to e.g. the poorly known worm-gear quark distribution $g_{1T}^{\perp}$.

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ACCESSING TMDS IN SEMI-INCLUSIVE DIS

In recent years, semi-inclusive deep-inelastic-scattering (SIDIS) processes are being explored by several experiments to investigate the nucleon structure through the measurements of new observables, not accesible in inclusive DIS. The detection of a final-state hadron in coincidence with the scatterd lepton has the advantage of providing unique information on the quark flavors involved in the scattering process ("flavor tagging") through the identification of the final state hadrons (e.g. π, K, etc), and allows to access new dimensions, such as the transverse-spin and transverse-momentum degrees of freedom of the nucleon. For instance, the recent first extraction of the chiral-odd transversity distribution $h_1^q(x)$ [1], the least known of the three fundamental leading-twist collinear parton distribution functions (PDFs), required the measurement of specific azimuthal asymmetries (the "Collins asymmetries") in SIDIS of unpolarized leptons off transversely polarized protons [2, 3, 4] and deuterons [5, 6]. Here x denotes the fraction of the longitudinal momentum of the parent (fast-moving) nucleon carried by the active quark.

When the transverse momentum $\mathbf{p}_T$ of the quarks is not integrated out, a variety of new PDFs arise, describing correlations between the quark or the nucleon spin with the quark transverse momentum, often referred to as *spin-orbit correlations*. These poorly known PDFs, typically denoted as transverse-momentum-dependent PDFs (or simply TMDs), encode information on the 3-dimensional structure of nucleons and are increasingly gaining theoretical and experimental interest. At leading-twist, eight TMDs, each with a specific probabilistic interpretation in terms of quark number densities, enter the SIDIS cross section in conjunction with a fragmentation function (FF) (see e.g. [7]).

When the polarization of the final hadrons is not regarded, this can be either the chiral-odd Collins function $H_1^{\perp}(z,\mathbf{K}_T^2)$, describing left-right asymmetries in the fragmentation of transversely polarized quarks, or the relatively well known spin-independent chiral-even $D_1(z,\mathbf{K}_T^2)$ FF. Here z and $\mathbf{K}_T$ denote the fraction of the energy of the exchanged virtual photon carried by the produced hadron and the transverse momentum of the fragmenting quark with respect to the outgoing hadron direction, respectively.

Among the leading-twist TMDs, the *'worm-gear'* $h_{1L}^{\perp}(x,\mathbf{p}_T^2)$ and $g_{1T}^{\perp}(x,\mathbf{p}_T^2)$ are those that have received the least attention so far. They are, nevertheless, very intriguing objects: $g_{1T}^{\perp}(x,\mathbf{p}_T^2)$ ($h_{1L}^{\perp}(x,\mathbf{p}_T^2)$) describes the probability of finding a longitudinally (transversely) polarized quark inside a transversely (longitudinally) polarized nucleon. Interestingly, they are the only two leading-twist TMDs whose corresponding Generalized Parton Distributions vanish in light-come quark models [8], and are found to be one the opposite of the other ($g_{1T}^{\perp}(x,\mathbf{p}_T^2) = -h_{1L}^{\perp}(x,\mathbf{p}_T^2)$) in various quark models [9, 10, 11, 12]. Despite their similarities, these two TMDs have a different behaviour under chiral transformations: $h_{1L}^{\perp}(x,\mathbf{p}_T^2)$ is chiral-odd and can be probed in SIDIS in combination with the Collins FF, while $g_{1T}^{\perp}(x,\mathbf{p}_T^2)$ is chiral-even and can thus be accessed in SIDIS combined with the unpolarized FF. Another important difference, especially from the experimental point of view, is that $h_{1L}^{\perp}(x,\mathbf{p}_T^2)$ can be accessed in longitudinal target A_{UL} single-spin asymmetries (SSAs), whereas in the case of $g_{1T}^{\perp}(x,\mathbf{p}_T^2)$ the longitudinal polarization of the active quark leads to A_{LT} double-spin asymmetries (DSAs), requiring both a longitudinally polarized beam and a transversely polarized target [7].

At leading-twist, the term of the SIDIS cross section that accounts for this DSA exhibits a $\cos(\phi-\phi_S)$ modulation in the azimuthal angles ϕ and ϕ_S, respectively of the detected hadron and of the target transverse polarization with respect to the lepton scattering plane and about the virtual-photon direction. In SIDIS experiments the worm-gear $g_{1T}^{\perp}(x,\mathbf{p}_T^2)$ can be accessed at leading-twist through the measurement of the DSA:

$$2\langle\cos(\phi-\phi_S)\rangle_{L\perp}^{h} = 2\frac{\int d\phi\, d\phi_S \cos(\phi-\phi_S)\sigma_{LT}}{\int d\phi\, d\phi_S \sigma_{UU}} = \frac{\mathcal{C}\left[-\frac{\mathbf{P}_{h\perp}\cdot\mathbf{p}_T}{|\mathbf{P}_{h\perp}|\,M}\, g_{1T}^{\perp,q}(x,\mathbf{p}_T^2)\, D_1^{q\to h}(z,\mathbf{K}_T^2)\right]}{\mathcal{C}\left[f_1{}^q(x,\mathbf{p}_T^2)\, D_1{}^{q\to h}(z,\mathbf{K}_T^2)\right]}\,, \tag{1}$$

where σ_{LT} denotes the cross-section difference for opposite target polarization states, $\mathbf{P}_{h\perp}$ is the transverse momentum of the produced hadron, $f_1{}^q(x,\mathbf{p}_T^2)$ is the unpolarized distribution function and $\mathcal{C}$ denotes a convolution integral over the intrinsic transverse momenta. Other Fourier components of σ_{LT} are the sub-leading twist contributions $\cos(\phi_S)$ and $\cos(2\phi-\phi_S)$, where the worm-gear $g_{1T}^{\perp}(x,\mathbf{p}_T^2)$ appears in convolution with the higher-twist $\tilde{D}^{\perp}(z,\mathbf{K}_T^2)$ FF besides several other contributions of PDFs and FFs.

In this work, preliminary results for the Fourier components of the DSAs, measured at the HERMES experiment with a longitudinally polarized beam and transversely polarized protons, are discussed for identified pions and charged kaons.

DATA ANALYSIS AND RESULTS

The data analysed was recorded during the 2003–2005 running period of the HERMES experiment using a longitudinally polarized 27.6 GeV positron/electron beam and a transversely nuclear-polarized hydrogen gas target internal to the HERA storage ring at DESY. The open-ended target cell was fed by a polarized atomic-beam source [13] based on Stern-Gerlach separation and RF transitions of hyperfine states. The nuclear polarization of the atoms was flipped at $1-3$ minutes time intervals. Scattered leptons and any coincident hadrons were detected by the HERMES spectrometer [14]. Leptons are identified with an efficiency exceeding 98% and a hadron contamination of less than 1%. A dual-radiator RICH allows identification of the charged hadrons (π, K, p) in the $2-15$ GeV momentum range. Events were selected subject to the kinematic requirements $W^2 > 10$ GeV^2, $0.1 < y < 0.95$ and $Q^2 > 1$ GeV^2, where W is the invariant mass of the photon-nucleon system, y is the fractional beam energy transfered to the target and $-Q^2$ is the squared four-momentum of the virtual photon. Coincident hadrons were accepted in the range $0.2 < z < 0.7$ only.

The three DSAs $2\langle\cos(\phi-\phi_S)\rangle^h_{L\perp}$, $2\langle\cos(\phi_S)\rangle^h_{L\perp}$ and $2\langle\cos(\phi-2\phi_S)\rangle^h_{L\perp}$ were extracted, together with six previously measured A_{UT} SSAs [3, 15, 16], in a maximum likelihood fit (unbinned in ϕ and ϕ_S) of the selected SIDIS events, based on the probability density function:

$$\begin{aligned} F(\phi,\phi_S) = 1 + P_T \left[2\langle\sin(\phi+\phi_S)\rangle^h_{U\perp}\ \sin(\phi+\phi_S)\ + ...\right] + \\ +P_T P_B \left[2\langle\cos(\phi-\phi_S)\rangle^h_{L\perp}\ \cos(\phi-\phi_S) + 2\langle\cos(\phi_S)\rangle^h_{L\perp}\ \cos(\phi_S) + \right. \\ \left. 2\langle\cos(2\phi-\phi_S)\rangle^h_{L\perp}\ \cos(2\phi-\phi_S)\right], \end{aligned} \tag{2}$$

where P_T (P_B) denotes the target (beam) polarization and "..." stands for the contribution of the five A_{UT} SSAs $2\langle\sin(\phi-\phi_S)\rangle^h_{U\perp}$, $2\langle\sin(3\phi-\phi_S)\rangle^h_{U\perp}$, $2\langle\sin(\phi_S)\rangle^h_{U\perp}$, $2\langle\sin(2\phi-\phi_S)\rangle^h_{U\perp}$, $2\langle\sin(2\phi+\phi_S)\rangle^h_{U\perp}$.

The systematic uncertainty, including contributions from acceptance effects, instrumental smearing, QED radiation and hadron misidentification, was evaluated as described in [3]. An additional 8.0% scale uncertainty, arising from the uncertainty on the beam and target polarization measurements, has to be considered.

The preliminary results for the $2\langle\cos(\phi-\phi_S)\rangle^h_{L\perp}$ asymmetry amplitudes are reported in Fig. 1 for pions and charged kaons as a function of x, z or $P_{h\perp}$. The results show a positive amplitude for π^- and a hint of a positive signal also for π^+ and K^+, whereas amplitudes consistent with zero are observed for π^0 and K^-. The positive amplitude for π^- reported here is similar to that recently measured at Jefferson Lab (E06010 experiment in Hall-A) but on a transversely polarized ^3He (i.e. neutron) target [17]. The amplitudes for the sub-leading twist DSAs $2\langle\cos(\phi_S)\rangle^h_{L\perp}$ and $2\langle\cos(2\phi-\phi_S)\rangle^h_{L\perp}$, not shown, are both consistent with zero for all measured mesons.

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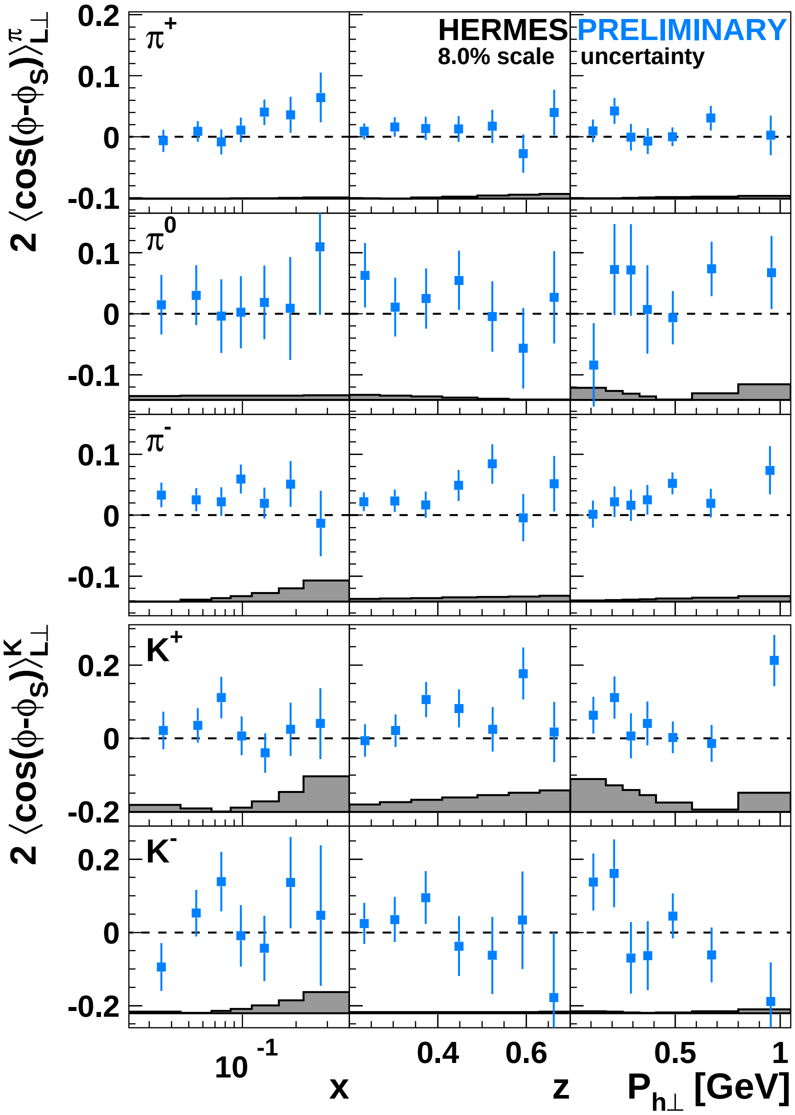

FIGURE 1. Preliminary results for the $2\langle\cos(\phi-\phi_S)\rangle^{h}_{L\perp}$ DSA amplitudes for pions and charged kaons as a function of x, z or $P_{h\perp}$. The shaded bands represent the systematic uncertainty. A common 8.0% scale uncertainty arises from the precision of the beam and target polarization measurements.

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